U.S. Department of Transportation

Federal Railroad Administration

RESEARCH RESULTS

FRA OFFICE OF RESEARCH, DEVELOPMENT & TECHNOLOGY

RR 22-13 | **August** 2022

Track Performance in Tunnels and Transitions with Under Tie Pads and Under Ballast Mats

SUMMARY

Railroads have begun to use under tie pads and under ballast mats in rail track construction to better distribute train loads, reduce the track modulus, and increase the tie-to-ballast contact area. Many tunnels, bridges, and track locations with a shallow ballast layer are strong candidates for under tie pads and under ballast mats. This report refers to under tie pads as UTP in the table and figures and as pad(s) in the text. Similarly, the report refers to under ballast mats as UBM in the table and figures and as mat in the text.

Under a contract with the Federal Railroad Administration (FRA), the University of Florida (UF) instrumented a section of the Virginia Avenue Tunnel in Washington, DC. The tunnel, built between May 2015 and June 2018, was designed and built with pads and mats. UF collected track data over the tunnel's first 20 months of service (i.e., July 2018 through February 2020). This data included measurements of track load distribution, tie movement, and tunnel floor pressure and vibration. The data captured track settlement during the first 6 months as the ballast consolidated. Total settlement was less than 0.157 in. (4 mm).

The load distribution and pressure data indicated that the pads and mats reduce track modulus and decrease the overall track stress state. Using mats and pads reduced the average force on the tie directly under the train axle by more than 10 percent compared to ties at the portal without mats.

BACKGROUND

Track with stiff support conditions can cause ballast breakdown, excessive vibration, differential track settlement, and increased track maintenance. These effects are even more pronounced at the approaches to railway structures where the track construction changes from subgrade to a stiffer structure like concrete. Creating a more gradual change in stiffness in these areas can reduce train dynamic forces and track degradation rates. Designers can add pads or mats to adjust the track modulus and create this gradual change. These elastomeric parts allow designers to tune the track stiffness for the best performance.

The Virginia Avenue Tunnel is a stiff track system transitioning from track on subgrade outside the tunnel to a concrete supported ballast track in the tunnel. The tunnel track is constructed with granite ballast and prestressed concrete ties at a spacing of 20 inches on a 36-inch-thick concrete floor. Outside the west tunnel entrance, the ballasted track changes from subgrade to asphalt over subgrade, to both asphalt and concrete layers over subgrade, and then to the tunnel 36-inch concrete foundation (Figure 1).

The track design included both mats and pads through the entire tunnel. The 0.039-inch-thick ballast mat was resin-bonded rubber with a polypropylene non-woven geotextile surface. It has a puncture resistance of 978 pounds. The 0.028-inch-thick pads were also resin-bonded rubber and attached to the tie bottom surface. Pads had a tensile strength of 138 psi. The track design included pads in the transition area outside the tunnel but no mats (Figure 1).

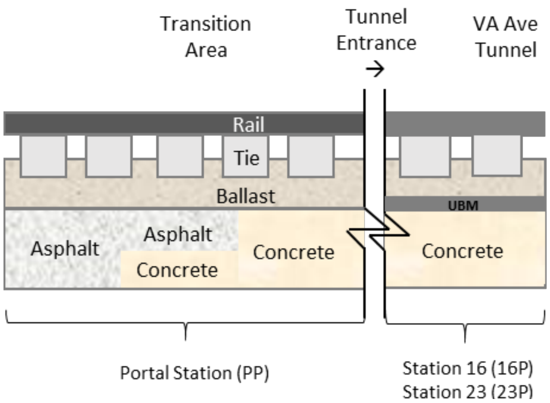

Figure 1. Transition from asphalt to concrete at the Portal location

OBJECTIVE

The objective of this project was to quantify track performance with pads and mats in the Virginia Avenue Tunnel. The project plan included a comparison test of track without pads and mats, but this arrangement was not available.

METHODS

UF researchers installed the instrumentation and monitoring system during tunnel construction. UF measured the pressure exerted by passing trains on the tunnel floor, load distribution in the track structure, track settlement, ballast moisture, and track geometry trends from railroad-supplied data.

UF installed instruments at three sections. Station 16 and Station 23 were inside the tunnel and a third station, Portal, was in the transition area outside the tunnel (Figure 1).

UF selected multiple sensors to assess the effect of the pads and mat. Accelerometers installed on top of concrete ties and on the concrete floor measured tie movement during train passes and provided insight into vibration energy transmission from the track to the tunnel floor over time. Moisture sensors quantified the volumetric water content in the ballast. Geokon® 3515 earth pressure cells were used to measure the distribution of tie-ballast and ballast-tunnel floor pressures (Geokon® 3515, 2017). Table 1 provides details on the locations of the pressure sensors installed at each section listed numerically 1 through 6.

Table 1. Locations of Geokon® 3515 pressure cells

#	Portal (PP) (no UBM)	Station 16 (16P)	Station 23 (23P)
1	On concrete-only base, below railseat	Embedded in tunnel floor, below center of tie (beneath UBM)	Embedded in tunnel floor, below center of tie (beneath UBM)
2	On concrete-asphalt floor, below railseat	On top of UBM, below center of tie	On tunnel floor, below railseat (no UBM)
3	On asphalt-only base, below railseat	On top of UBM, below railseat	On top of UBM, below railseat
4	Embedded in tie over asphalt-only base, below railseat (over UTP)	Embedded in tie, below railseat (no UTP)	Embedded in tie, below railseat (no UTP)
5	Embedded in tie over concrete-only base, below railseat (over UTP)	Embedded in tie, below center of tie (over UTP)	Embedded in tie, below center of tie (over UTP)
6	-	Embedded in tie, below railseat (over UTP)	Embedded in tie, below railseat (over UTP)

Laser sensors measured horizontal and vertical tie displacement to quantify the track movement during train passes and long-term track settlement (Figure 2). By using two sensors at each location, with each one pointed at targets with known inclination, researchers could calculate both vertical and horizontal displacements.

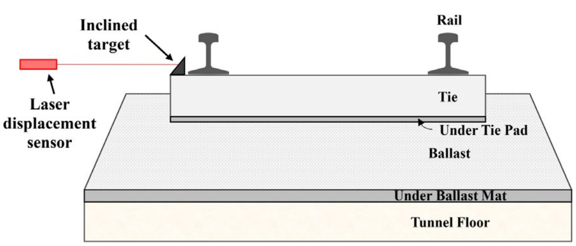

Figure 2. Configuration of a laser displacement sensor

RESULTS

UF collected data on 2,349 train passes between July 16, 2018, and February 26, 2019. The peak pressure generated under the third axle of the first locomotive for each train was selected to quantify the distribution of axle loads and the response of the track. Figure 3 shows the moving average pressure measurements at the portal transition area outside the tunnel. Researchers compared data from three locations: concrete-only base, asphalt and concrete base, and asphalt-only base. The average pressure increased with track stiffness. The lowest pressures were on the asphalt-only base. The pressures on the concrete-only base were roughly two times higher. The pressures on the asphalt and concrete base were roughly 2.7 times higher, possibly from to dynamic loads caused by the change in stiffness in this area.

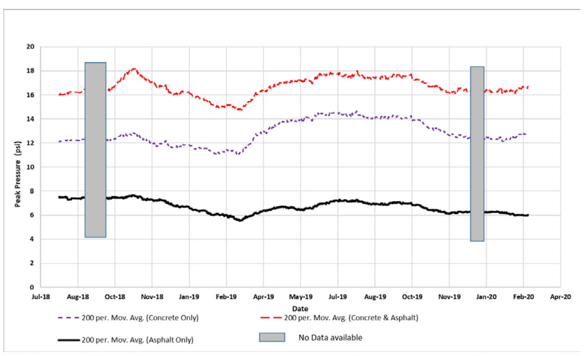

Figure 3. Moving average of peak pressure measured over time in the portal transition area

Figure 4 compares tie-ballast pressure at three locations: (1) Station 16, (2) Portal transition area with concrete-only base, and (3) Portal transition area with asphalt-only base. All locations included pads, but only Station 16 also had mats. Researchers compared the pressure at Station 16 with the Portal section to assess the effect of the mats. Figure 4 shows the pressure distribution was similar for the sensors at the transition locations even though they had different track structures. The pressure at Station 16 was more evenly distributed with a 10 percent decrease in the peak pressure. The team credited this to reduced track stiffness resulting from the mats.

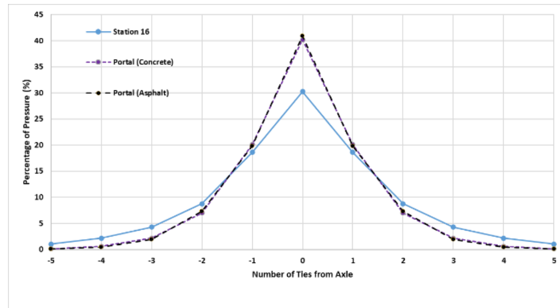

Figure 4. Pressure distribution by tie location

Figure 5 shows the laser displacement data at Station 16. The track experienced 0.156 in. (4 mm) of vertical settlement over the 20-month study period. The maximum settlement rate occurred during the first 6 months of train operation, probably due to ballast consolidation. There is no data to explain the dip and rise between April and May 2019. It is possible that track maintenance was performed, but this is unconfirmed. The track experienced minimal settlement after May 2019. The low settlement rate indicates a stable track structure that should reduce track tamping and other maintenance requirements.

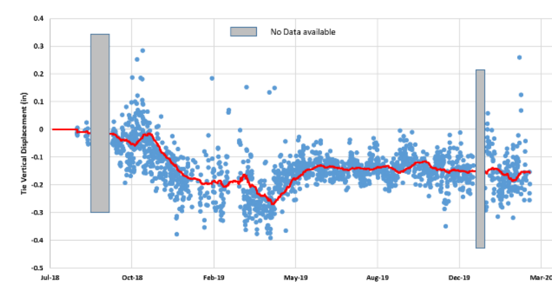

Figure 5. Track settlement at Station 16

CONCLUSIONS

Based on the data collected over the 20 months of initial service of the tunnel, researchers drew the following conclusions:

- Mats helped distribute axle forces across more ties by reducing overall track stiffness.

- The track settled 0.157 in. (4mm) over the first 6 months and then stabilized.
- Pads and mats helped produce a stable track structure. The stable track system should help reduce track tamping frequency and ballast breakdown.

Interested readers can read Track Performance in Tunnels and Rail Transition Areas with Under Tie Pads and Under Ballast Mats for the full report.

FUTURE ACTION

Future research will examine the influence of mats and pads on track load distribution and examine if one or the other improves track performance more. Computer based simulation of track with and without pads and mats are planned to better understand the differences in performance of the track. This information could help plan future tests to support design and specification of pads and mats.

REFERENCES

Geokon®. (2017). Instruction Manual Model 3500 Series Earth Pressure Cells. Lebanon, NH.

ACKNOWLEDGEMENTS

The authors acknowledge CSX Transportation and Pandrol for providing access to the tunnel site and aiding with instrumentation and fiber optic networking. The advice and help of Chris Moale and Damon Smith from CSX Transportation, Dillon Benros from Pandrol, and Ted Sussmann and Cameron Stuart from FRA is gratefully acknowledged. Mr. T. J. Watts provided advice on placement of sensors underneath ties.

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KEYWORDS

Under tie pads, under ballast mats, transition areas, tracks, ties

CONTRACT NUMBER

693JJ618C000001